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California HIgh school Cosmic ray ObServatory (CHICOS)

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ABSTRACT

The California HIgh school Cosmic ray ObServatory (CHICOS) is a collaborative project involving Caltech, Cal State Northridge, UC Irvine, and local high schools to site a large array of particle detectors in Southern California. The detectors are located on school rooftops, and utilize the power and network infrastructure available at the schools. The main scientific goal is to study cosmic rays at ultra-high energies $E>10^{19}$ eV. We have fielded a total of 23 sites so far, and are beginning to collect data as we continue to deploy additional sites. We have observed our first evidence of extended air showers in coincidence with a local high school. The anticipated performance of the initial array and the potential for future expansion will be discussed.

Keywords: Particle Astrophysics, Ultra-high Energy Cosmic Rays

1. Introduction

In recent years there has been a great deal of interest in the study of ultra-high energy cosmic rays (UHECR). The energy spectrum of such cosmic rays continues to decline roughly as E^{-3} and so the flux becomes extremely small at the highest energies. (The integrated flux above 10^{20} eV is about 1/(100 km^2)/year.) The recent development of large acceptance air shower detection systems for energies above 10^{19} eV has enabled the detection of significant but limited samples of such particles. The AGASA experiment has published data[1] indicating that the spectrum continues beyond 10^{20} eV. The AGASA results appear to be inconsistent with more recently reported preliminary results from the HiRes air fluorescence experiment[2]. The HiRes experiment observes a smaller flux above 10^{20} eV, but does observe a few events in this region.

It was generally expected that there would be a dramatic decrease in the flux above 10^{20} eV due to inelastic scattering (e.g., pion photoproduction) with the cosmic microwave background, known as the GZK effect[3]. The apparent observation of events in this energy region has generated substantial interest and much speculation[4,5]. It is possible that the observed events are not due to primary high-energy protons (as is generally assumed) but exotic new particles. Alternatively, it may be possible that the UHE protons are generated at relatively nearby (say < 20 Mpc) astrophysical sites[6]. There is also some evidence of clustering of events in recent AGASA data[7], which would be an indication that there are actually point sources of UHECR. There is widespread consensus that additional data are needed to further our understanding of the nature and origin of these extraordinary events at ultra-high energies.

With many decades of development, ground arrays of scintillation counters have proven to provide a reliable, stable, and effective method to sample air showers. The goal of the CHICOS project is to utilize the existing infrastructure in a large urban area like Los Angeles to field such an array. In particular, the L.A. school system offers internet connections, power, shelter, and enthusiastic participants, providing an excellent opportunity to develop such a large array. Very capable PC's, GPS receivers, and high-speed computer network connections are all recent technical developments that are now readily available at low cost. This cost-effective approach should provide a new method to complement the capabilities of the Pierre Auger Observatory[8], under construction in Argentina. In addition, locating the detector stations at LA area high schools will enable the participation of high school teachers and students: CHICOS will provide a novel mechanism to engage this ethnically and racially diverse student population in ongoing frontier scientific research, and we are developing an associated educational program as part of the project.

Particle Astrophysics Instrumentation, Peter W. Gorham, Editor,
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Over the last year, we have begun fielding a pilot array of 80 sites using detectors from the decommissioned CYGNUS array. This pilot array should be essentially completed during 2002, and will begin to produce interesting data on extended air showers as we gain operational experience. The general concept, technical details, present status, and future plans of the CHICOS project are discussed in the following.

2. CHICOS Concept

The performance of a ground array like CHICOS for the study of extended air showers depends upon basic parameters of the network, particularly the size of the detectors fielded at each site and the average areal density of the sites. In our approach, we employ two CYGNUS scintillator detector units (with a total area of typically 2 m^2) per site. Each site is located at a Los Angeles area school, usually a high school or middle (junior high) school. Fig. 1 shows a relatively small part of the Los Angeles area centered at Caltech in Pasadena to illustrate the range of site densities that are achievable. Using only high schools (HS) and junior high schools (JrHS) we achieve a density of about 1 site per 3 square kilometers. The use of some elementary schools in a limited area would allow us to reach up to 1 site per 1.5 km^2. The dotted box (132 km^2) indicated in Fig. 1 contains 81 sites and has been used in simulation calculations below to evaluate the performance of the CHICOS array as a research facility.

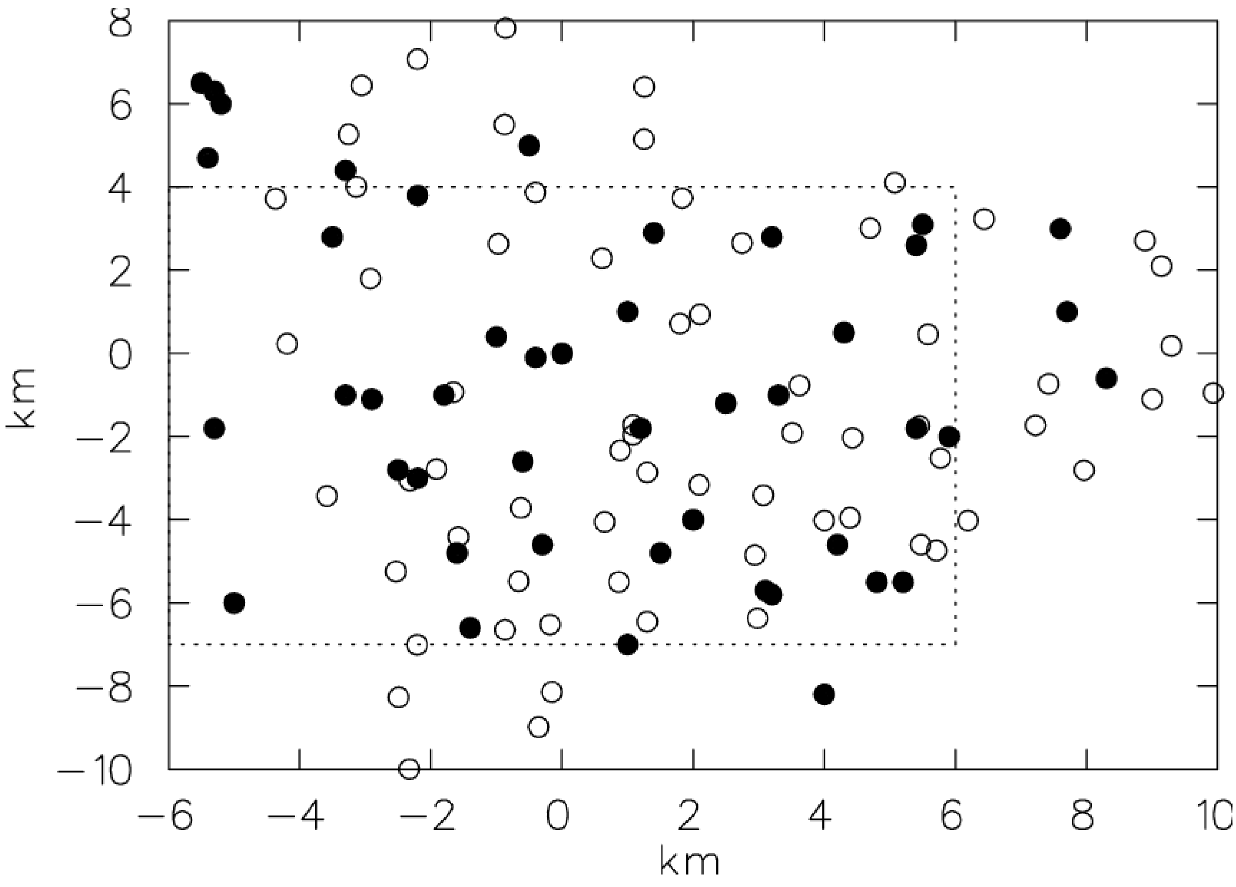

Fig. 1: Potential sites for CHICOS in the Pasadena area. The distance scale is kilometers and Caltech is located at (0,0). This figure shows a total of 45 high school and junior HS sites (filled circles), and an additional 66 elementary school sites (open circles) . Data corresponding to the regions in the lower and lower-right portions of the plot are incomplete and so many potential school sites are not shown in those areas.

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The AGASA version of the NKG formula was used to generate showers in the boxed region shown in Fig. 1 for zenith angle < 45 degrees. The trigger criterion was at least 4 hits in one ($2m^2$) site and a minimum of 5 sites hit. The resulting aperture vs. energy is shown in Fig. 2.

One can see from Fig. 2 that the geometric aperture is a good approximation for the energy region $E>10^{19}$ eV when one includes elementary school sites, and that HS/JrHS sites are sufficient to maintain this condition above 5×10^{19} eV. Our basic strategy is to utilize all available sites within a modest area of 50-75 km^2 and deploy sites at a lower density (corresponding to only HS/JrHS sites) over a wider area to gain sensitivity in the higher energy region. The higher density region would be located close to Caltech, where we can more easily maintain the sites without much assistance from school personnel. The wider area using HS/JrHS sites would encompass regions in the San Fernando Valley and elsewhere, and the assistance of the high school teachers will be of significant value (although not required) in maintaining the equipment over such a larger area.

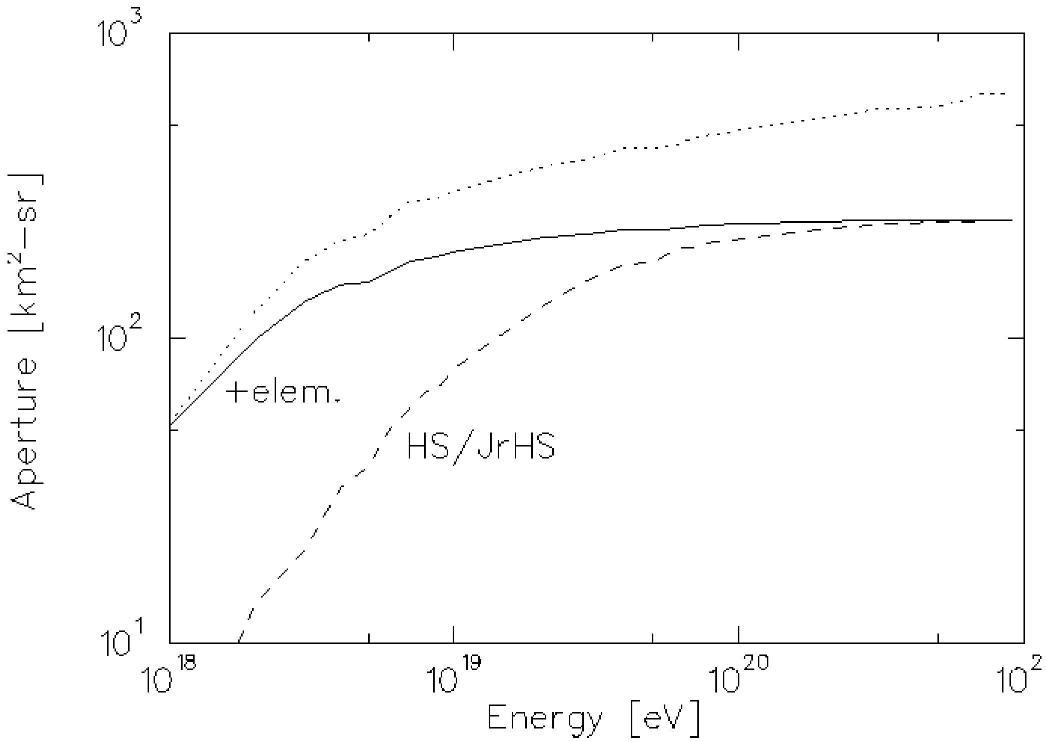

Fig. 2: Estimated aperture for the example array of Fig. 1. The dotted line corresponds to all 111 sites in Fig. 1, whereas the solid and dashed lines corresponds to showers centered within the boxed (132 km^2) region. The dashed line corresponds to only the high schools and junior high schools and the solid line includes elementary schools.

Based on these simulations, the expected event rates for a HS/JrHS array of 80 sites in the San Gabriel and San Fernando Valleys are given in Table 1 as a function of energy threshold.

Preliminary reconstruction studies have been performed. These indicate that for an energy of 3×10^{19} eV the higher density region (including elementary school sites) would enable reconstruction of shower size with about 17% statistical accuracy. Utilizing only HS/JrHS sites would enable reconstruction of the energy scale of such showers with 30% relative accuracy. Thus, we expect performance comparable to the AGASA array. We note that the diameter of

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showers associated with 10^{20} eV primaries is comparable to the lateral dimension of AGASA. CHICOS aims to cover a substantially larger area (at lower site density) to reduce array boundary effects that may contribute to reconstruction errors for large showers.

Energy Threshold	Aperture	Events/year
10^{18} eV	10 km^2-sr	600
10^{19} eV	200 km^2-sr	120
10^{20} eV	500 km^2-sr	3

Table 1. Estimated aperture and event rates for three different threshold energies for an 80 site CHICOS array.

3. Site Hardware

The basic concept for the CHICOS detector station is shown in Fig 3. Each station is configured with 2 detectors to facilitate coincident triggers, and operates autonomously with GPS time stamping (accuracy < 50 nsec). Data are stored and transferred to Caltech via internet once per day (during the night).

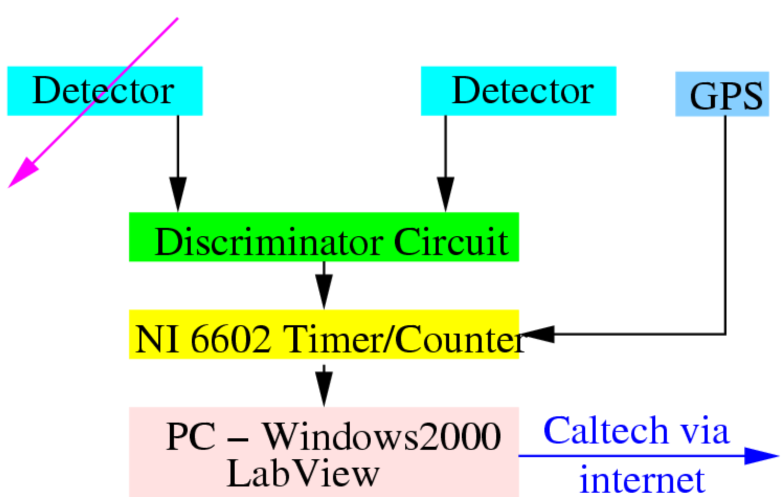

Fig. 3 CHICOS detector station concept.

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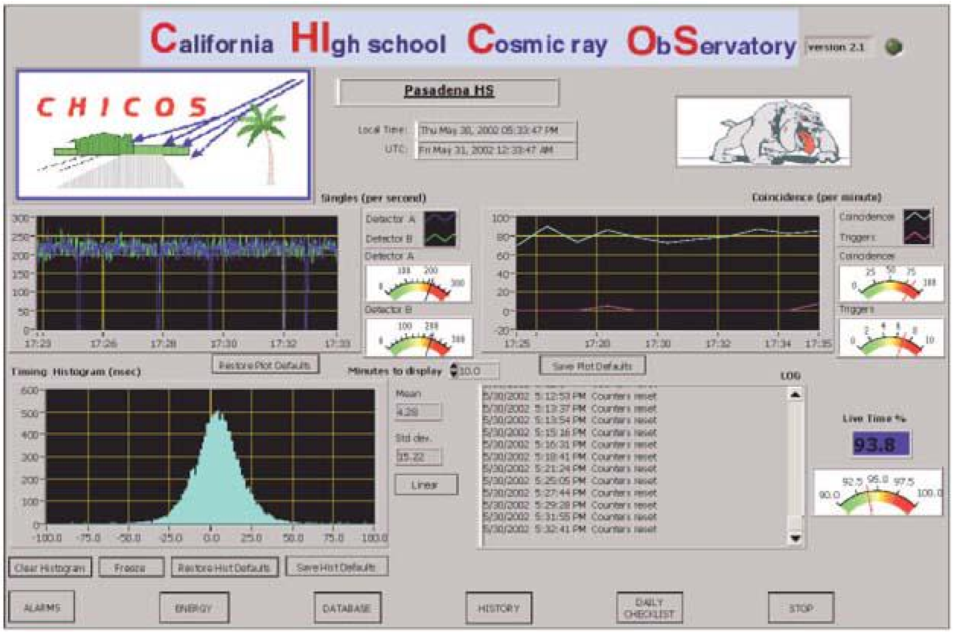

Fig. 4 CHICOS front panel LabView display.

The detectors used in this phase of the project are refurbished scintillation counters from the decommissioned CYGNUS experiment. Each detector is a plastic scintillator, typically ~1 m^2 and 10 cm thick, located at the bottom of a conical weatherproof enclosure. Scintillation light is diffusively reflected inside the enclosure and collected by a photomultiplier tube at the tope of the conical enclosure. We have instrumented these detectors with 3 inch photomultiplier tubes from the decommissioned Palo Verde neutrino experiment. The photomultipliers are powered by Brandenburg high voltage supplies mounted inside the detector housing, with high voltage control via a low-voltage (0-9 volts) control signal. Thus the detector units receive only low-voltage (+/-15V) power over multi-conductor cables. The detector signals are shaped by an RC shaping circuit to have a 50 nsec decay time and are transmitted to the discriminator circuit by RG58 cable (typically 50 feet long).

The discriminator circuit is a two-stage fast TTL comparator, set to fire at -10mV and is updating so that the pulse width corresponds to the time over the -10mV threshold (minimum pulse width is 40 nsec). The dual discriminator circuit and the controls for the high voltages are contained in a ``CHICOS Electronics Unit'' (CEU), located in the classroom or lab of the school along with the CHICOS computer and GPS receiver. The CEU circuit is manually assembled on a printed circuit board, and can be built by high school students and teachers.

Timing of the detector signals and the GPS receiver signals is facilitated by use of National Instruments 6602 timer/counter card. This 8 channel unit incorporates an 80 MHz clock and each channel is programmable for a variety of relevant timing/counting tasks. We presently utilize 2 NI-6602 cards (one for each detector) per site.

The computers utilize the Windows 2000 Professional operating system, a LabView executable to acquire the data, and SynTac software for the GPS system. The LabView and SynTac software are imbedded in loops to restart the code if there are any hangups. The data transfer is implemented via scheduled FTP tasks. An example of a front panel display, available at every site, is shown in Fig. 4.

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4. Present Status

Following successful operation of this system in our lab at Caltech, we began deployment at high schools in the San Fernando Valley in September 2001. We continued in early 2002 with deployment in the Pasadena area, and the present status is shown in Fig. 5. We presently have 23 sites installed and operational, and are planning to continue deployment of at least 40 additional sites during the remainder of 2002.

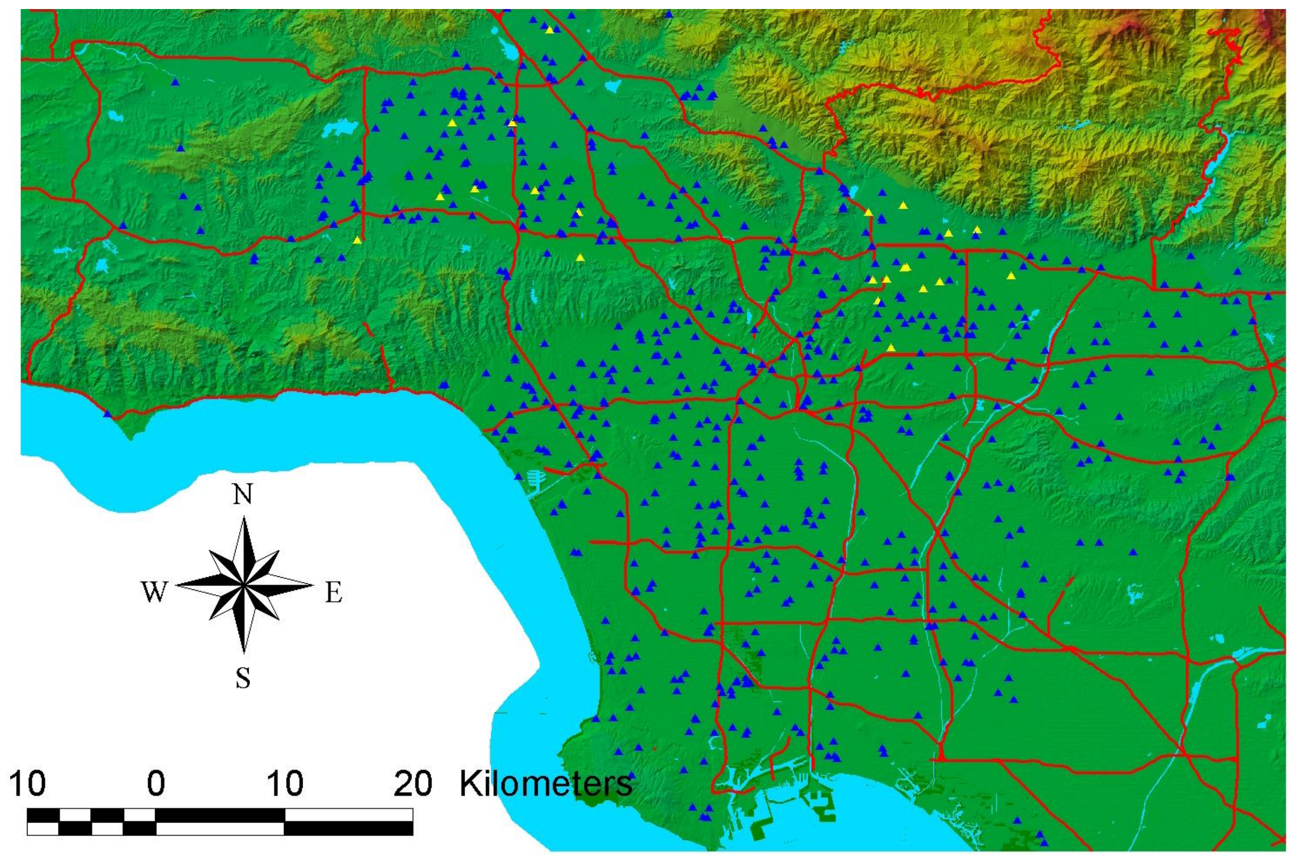

Fig. 5 Operational CHICOS sites are shown as light triangles. Additional potential CHICOS sites (about 800) are shown as darker triangles, although this database is still under development and many additional sites are anticipated in the future.

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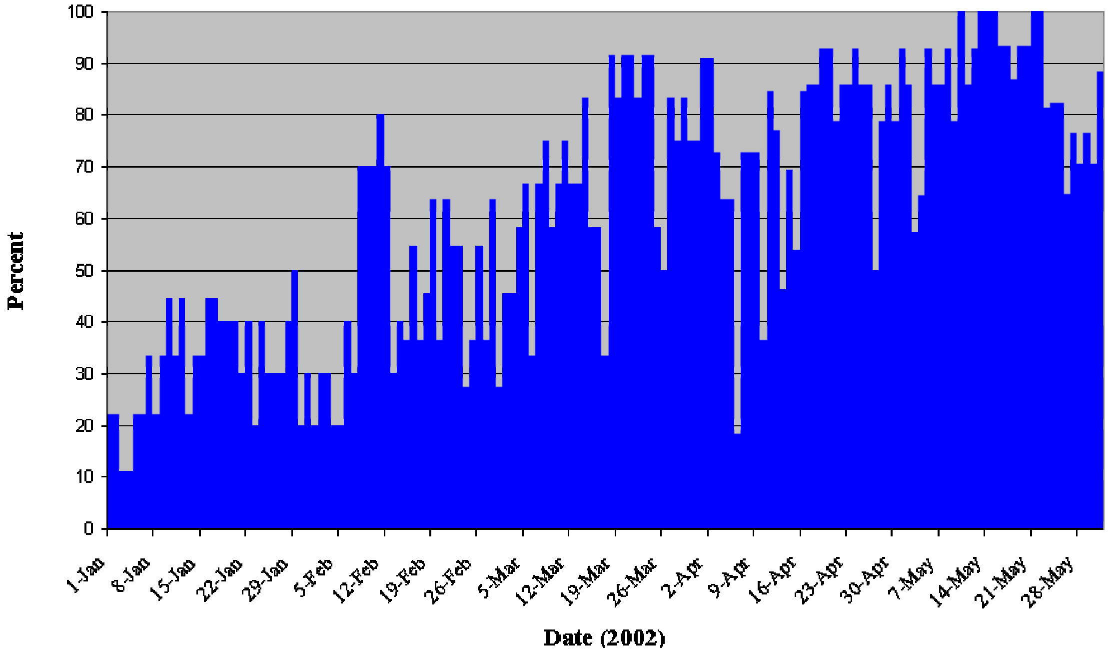

Fig. 6 Percentage of installed CHICOS sites transfering all data.

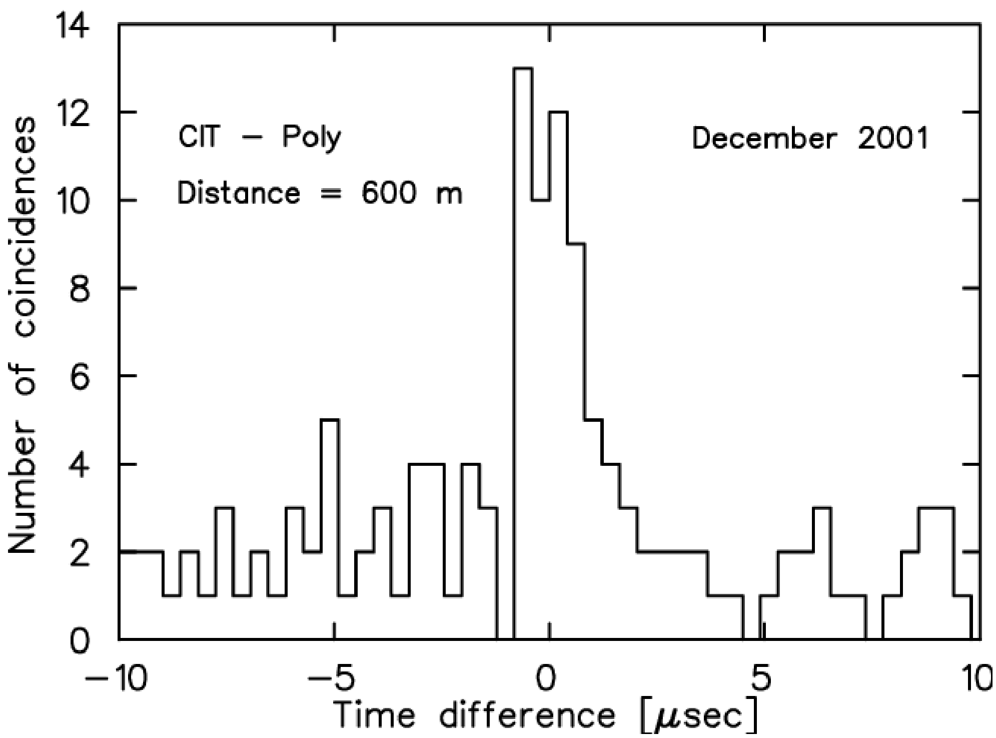

Fig. 7 Histogram of time differences for coincident events between Polytechnic School and Caltech.

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The 23 installed sites are providing us with valuable experience in operating sites in the field and in the transfer of data. We have encountered some difficulties with light leaks, software reliability, computer reliability, and data transfer. Often with the assistance of high school personnel, we have made significant progress in improving the reliability of our systems. We have implemented an electronic logbook with a separate section for each school site and developed software to document the daily reporting status of all active sites. The fraction of installed sites reporting all data has increased steadily since the beginning of 2002, as can be seen in Fig. 6.

We have begun to observe evidence of extended air showers in the data we are accumulating. The closest site to Caltech is Polytechnic School, about 600 meters away from the Kellogg Lab. We detect triggers (both detectors fired with at least 4 total equivalent throughgoing muons) at one site in coincidence with singles events (one detector fires) at a frequency of 10-20 per day. A plot of the time difference for some data is shown in Fig. 7.

We have seen up to 6 independent sites all fire within 100 μsec over extended areas. It is difficult to perform quantitative shower reconstruction and analysis at this point due to the sparsity of the current CHICOS array. However, the data do improve steadily as we deploy more sites.

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